Final Report: Imaging Spectroscopy of Coastal Habitats within the Monterey Bay National Marine Sanctuary

Submitted by:

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Introduction

The specific objective of the proposed study were to evaluate the utility of hyperspectral imagery of coastal environments within the MBNMS obtained by the PHILLS to map important features of optically shallow waters, including (i) bathymetry, (ii) substrate type (e.g. sand vs. rock) and extent of benthic vegetation, surface kelp cover, including-the ability to differentiate between canopies of giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis lutekeana*) as well the condition or "health" of kelp canopies (SIMoN Program Proposal 2002, Principal Investigator, R. C. Zimmerman, Co-Principal Investigator, W. P. Bissett).

The funding for this proposed study was to augment the funding of the CSU California **C**enter for **I**ntegrative **C**oastal **R**esearch and **E**ducation (CI-CORE), whose principal mission is to build a coastal ocean observatory along the entire 1200 miles of California coastline. This funding augmentation had multiple aims. The first was to cover the approximate 60 hours of aircraft flight time on a NOAA aircraft. The second aim was to demonstrate the need for regular NOAA service on the West Coast of the US, as nearly half of our flight request was in transportation cost from NOAA Aircraft Operation Center (AOC), located in Tampa, FL. By demonstrating the utility of frequent hyperspectral aircraft surveys, as well as the other aircraft needs by MBNMS, it was hoped that future aircraft needs on the West Coast could be bundled in some way to reduce total costs to all NOAA services. The third major aim of this proposal was to demonstrate the linkages between NOAA programs (CI-CORE is a NOAA program), such that resources, data, and data products could be efficiently generated to effectively monitor and manage of California coastal zone.

The deliverables from this project were to include:

1) A description of operating conditions required to achieve 2 m spatial resolution of nearshore imagery with the PHILLS instrument, including flight altitude, effective aircraft ground speed and resulting image width, or lateral coverage, in meters.
2) Copies of all geo-rectified hyperspectral imagery obtained during the overflights, in a format compatible with most geospatial analysis software (ENVI, ARCView, etc.).
3) Maps of bathymetry for selected optically shallow areas in a target area.
4) Detailed distribution maps of sand, bare rock and vegetated substrate (mostly rock) for selected optically shallow areas in a target area.
5) Maps of kelp cover for surface canopies, including an evaluation of:
    i. the extent to which bull kelp and giant kelp can be distinguished from each other in the hyperspectral imagery and
    ii. the extent to which condition or "health" of the kelp canopy can be determined from the hyperspectral imagery.

The target area for these deliverables was selected to be San Luis Bay, CA, as this was the best set of imagery and ground truth available from the October 2002 data collection. It should be noted that the vast majority of funding for the development of these deliverables were obtained through CI-CORE. The funding under the SIMoN project was strictly for NOAA AOC flight time.

In previous reports (see CI-CORE Progress Reports, January and July 2003), we have outlined our collection, archiving, distribution, and radiometric calibration progress. Besides radiometric calibration, the two most important items in making hyperspectral remote sensing data of use are geo-rectification and atmospheric correction. It is in these two areas that we have focused our recent efforts in the processing of the CI-CORE October 2002 experiment data stream. With the data geographically and atmospherically corrected, we have made some significant progress in developing the algorithms necessary to transform the hyperspectral imagery into maps of the benthic environment. We have also built two separate yet complimentary systems to disseminate the collected data and products over the internet.

Methods and Results

The ability to connect imagery data to physical positions on the ground is critical to the usefulness of any geospatial dataset. This process is not a trivial matter for airborne remote sensing instruments. Unlike ground measurements, the imagery data are collected some distance away from its target during very quick time intervals. Not only does this require a high level of precision in the mathematics that model the sensor and its relationship to the aircraft's attitude, but also a high level of confidence in the instrument that is collecting the aircraft's movements. To monitor the aircraft and thus the sensor's position and projection, we employ the CMIGITS-II, Inertial Navigation System (INS) and Global Positioning System (GPS), developed by Boeing. This instrument's data streams are recorded during the flight and used to geo-rectify the imagery post experiment. Since matching up time stamps between the two data sets (imagery and attitude/location) is critical in generating the sensor's projection model, we employ a GPS timing card (TrueTime) on the computers collecting the data to insure no clock drift takes place.

We utilize a Naval Research Laboratory (NRL) model to generate the relationship between the sensor, the aircraft, and the imaged ground. To train the model, a flight needs to be performed over an area of minimal vertical relief that contains physical landmarks whose positions are known and are distinct enough to resolve in the aerial imagery. For the fall 2002 CI-CORE study, we chose Monterey and Paso Robles Airports as our study sites. Airports are ideal because they are both relatively flat and have large, linear, distinct features.

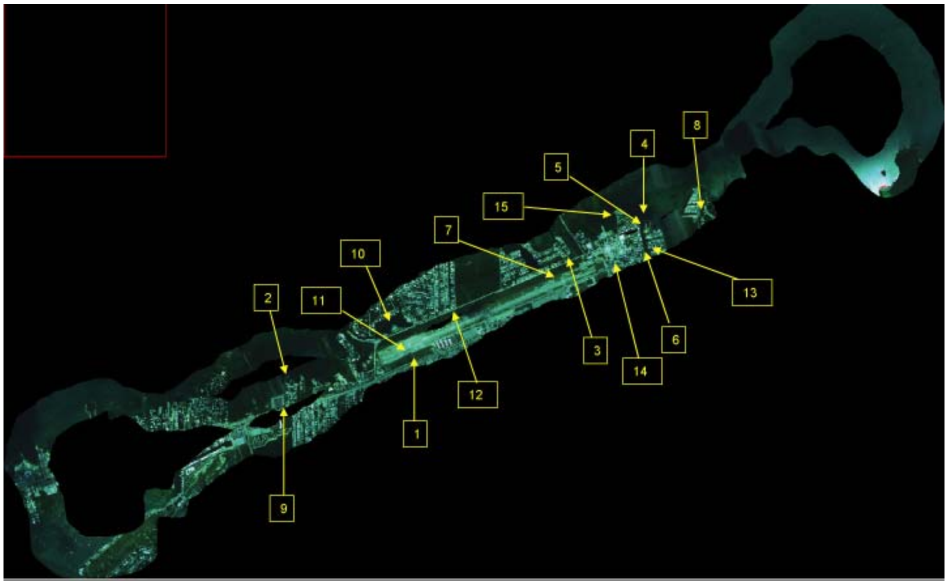

Figure 1: Ground points from Marathon Airport, FL used for geo-rectification

Unfortunately, we encountered problems at both of these sites. The air traffic at Monterey proved to be prohibitive, and we were unable to get to a low enough altitude to make proper measurements. Maintenance issues (there was an emergency FAA notice that grounded the aircraft for almost 2 weeks) with the aircraft preempted further geo-location collections in the area, and thus, restricted us from finding another suitable study site in the Monterey vicinity. (Note: During the spring 2003 flights, we utilized the Marina Airfield. Its relatively low use level was ideal for our needs.)

Paso Robles, on the other hand, had a different issue. Being that it was inland and situated near mountains inhibited us from collecting the DGPS signal. DGPS is a ground based line of sight transmission signal used to better constrain the GPS data. Throughout the fall study, we had several issues with less than optimal DPGS signal strength. We have addressed this by installing a high powered DGPS antenna on the aircraft in time for the spring collect. We did not witness any DGPS dropout during the spring study.

Figure 2: Geo-corrected line for Ci-CORE October 17, 2002 flight day - San Luis Bay, CA

Although it would have been ideal to collect useful geo-rectification training data in California, we were fortunate to have scheduled a flight in the Florida Keys immediately following the CI-CORE flights. Since the sensor was not disturbed between these collects, the aircraft-sensor relationship that was determined for the Keys work also is applicable to the California collects. As can be seen in Figure 1, we collected data over the Marathon Airport in Marathon, FL. By relating points in the PHILLS II to the known positions on the ground as determined by a USGS Ortho-photographic Quarter Quadrangles (DOQQ), the sensor model was determined at this location.

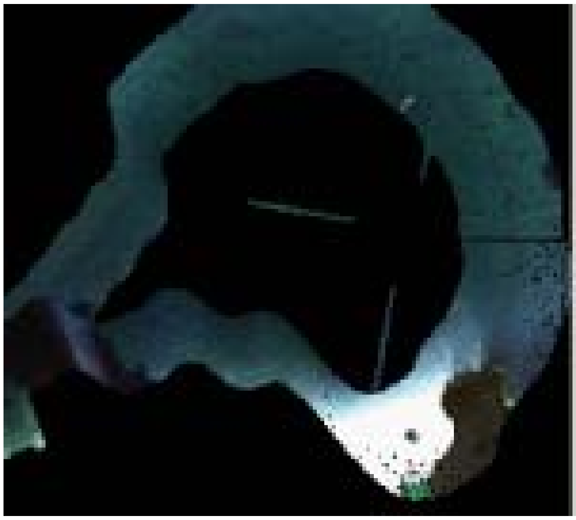

Figure 3: 'Cross' pattern as a result of southward bound heading

This model in turn allowed us to geo-rectify the CI-CORE imagery automatically without any additional ground points (Figure 2).

Two other issues were also addressed with regards to geo-rectifying the PHILLS II imagery. First, the NRL model we have been utilizing generated unusual "cross" patterns when the aircraft flew at certain headings (Figure 3). This bug was tracked down and found to be caused whenever the aircraft's heading was exactly southward bound. This issue has been fixed and all data have been rerun through the model. The other issue dealt with the direct application of the geo-rectification data to the imagery. We scheduled our flights with an altitude and speed that would generate imagery with a ground pixel resolution of approximately 2 meters. However due to turbulence and fluctuating wind speeds at altitude, we were not always able to collect the data at the interval we had planned. The software we use to make the final projection of the data (Research Systems' digital image processing package ENVI) was not equipped to handle the variability in the data's gridding that these fluctuations produced. It in turn produced an image with a lot of gaps (Figure 4). Due to the unaesthetic nature of this product, we were forced to resample the data to a 4 meter pixel size prior to distribution, which in turn, greatly reduced the effects of the data gap. This, however, was unacceptable. By resampling to 4 meters, we were in essence reducing the data density by 75%. To address this, we have developed a program that interprets the data pointers (not the data itself), and thus, fills in the gaps within the geo-location look up table. The data are then projected on to this new surface and the vast majority of the gaps are eliminated while the original spatial resolution of the data are maintained (Figure 5). It should

Figure 4a: Geo-corrected line for Ci-CORE October 17, 2002 flight day - San Luis Bay, CA at 2 meter spatial resolution

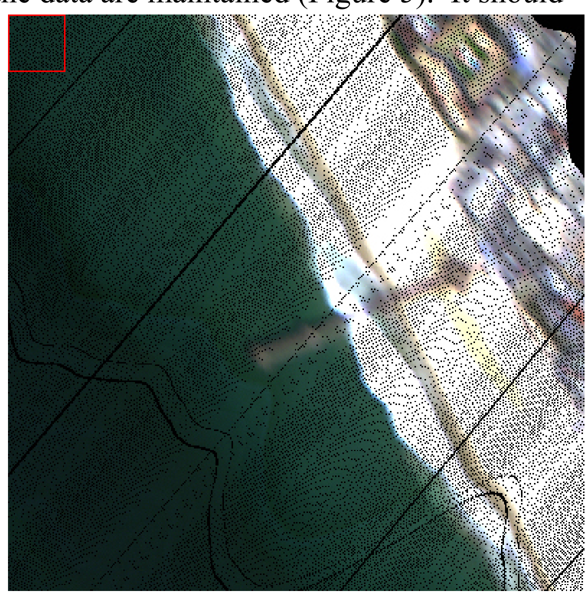

Figure 4b: Zoomed in image of San Luis Bay dataset. Area corresponds to red box in Figure 4a

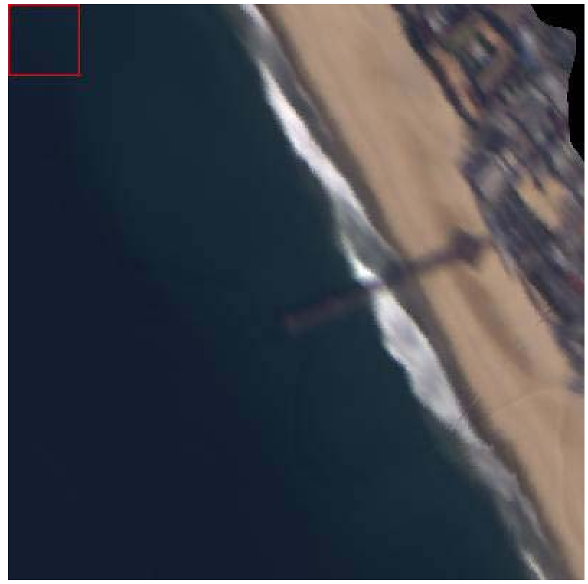

Figure 5a: Geo-corrected line for Ci-CORE October 17, 2002 flight day - San Luis Bay, CA at 2 meter spatial resolution after locational interpolation was performed.

Figure 5b: Zoomed in image of San Luis Bay dataset. Area corresponds to red box in Figure 5a

be noted that shortly after the completion of the work, a new version of ENVI was released that also addressed this issue. In the development of this work, we also improved the efficiency in which this procedure is performed on the data. We now witness nearly a 50X increase in the speed of this procedure. This increase is even more significant when considering the enormous size of the data sets we are processing (100s of gigabytes per experiment).

The second issue addressed with the fall 2002 CI-CORE dataset dealt with atmospheric correction. Water is a dark target for optical remote sensing instruments. Depending on the altitude of the instrument and the wavelength range collected, the atmosphere can comprise of 80-100% of the signal collected. The dominating effects of the atmosphere for coastal and oceanic remote sensing make its removal a delicate process. In deep oceanic water, the removal of atmospheric effects is greatly helped by the fact that there is essentially zero water leaving radiance in the infrared (IR) wavelengths (with the exception of certain blooms of phytoplankton). Deep waters do not embody the visible effects of sediment resuspension from interactions with their bottom layer or the effects of sediment rich river outflows. Thus, any return in the IR can be attributed to the atmosphere only (black pixel) and the removal of atmosphere in the visible wavelengths may be easily accomplished. Unfortunately, the effects of high particulate loads are frequently seen in coastal waters. These effects, as well as bottom effects and surface vegetation, were seen in the near-shore CI-CORE waters and result in detectable IR returns. This makes the atmospheric model selection and the accurate retrieval of water leaving radiance very difficult.

In an attempt to atmospherically correct the data sets collected, we employed TAFKAA, an atmospheric correction program developed by NRL. TAFKAA is a derivation of ATREM, the standard atmospheric correction model for hyperspectral remote sensing data sets. TAFKAA utilized sets of predetermined tables of the atmospheric effects on the radiance measured by the PHILLS II. Guided by the solar and sensor geometries and environmental conditions, it returns a solution which it applies to the PHILLS II data set. The sensor and solar geometries are directly derived from the data's time stamp and positional information. The environmental conditions, on the other hand, need to be selected by the user. The parameters that TAFKAA utilizes are: ozone concentration, aerosol optical thickness, water vapor, wind speed, aerosol model, and relative humidity. Although there are instruments that measure these parameters, we did not have access to any of them during this study.

Rather than making educated guesses at the parameters' values, we built a genetic algorithm (GA) to aid in the selection of the most appropriate atmospheric conditions and its affect on our remote sensing data. The GA intelligently searched the atmospheric parameter space by testing different combinations of atmospheric constraints. Each set was evaluated by running it through TAFKKA and comparing the output to ground truth data. A set of ground stations were employed in the study so not to limit the atmospheric correction model. In doing so, however, an assumption of a homogeneous atmosphere for a particular day across the study sites had to be made. Parameter sets that produced results that resembled the ground truth data were maintained and evolved; the remaining sets were eliminated. The ground truth data were collected by Dr. Zimmerman's team simultaneous to the flights. Because the instrument used by Dr. Zimmerman did not directly measure remote sensing reflectance (the output of TAFKAA), HYDROLIGHT, a hydro-optical model, was utilized in the conversion of the data. This synthesis was performed by Dr. Zimmerman's team.

Due to the discretization of the parameter space for the GA, there were nearly 75 million possible solutions to test. Many, however, are unrealistic. The GA tested only about one quarter of one percent of the total possible. But in doing so, it determined a realistic atmospheric model that produced PHILLS remote sensing reflectance values that closely resembled the ground truth spectra (see Table 1 and Figures 6a-b). With these values, the October 17th data over San Luis Bay were atmospherically corrected to yield estimates of remotes sensing reflectance.

The GA procedure requires ground targets to be measured simultaneous to the collect. Although there were nine ground truth stations collected during the San Luis Bay flight, we only

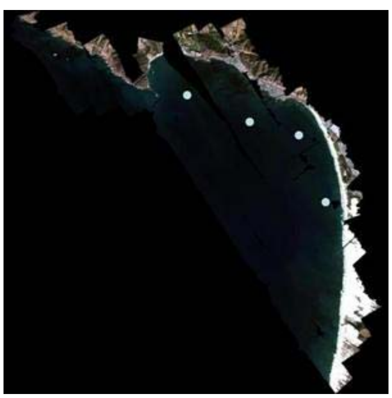

Figure 6a: A PHILLS II, three band mosaic of the San Luis Bay, CA site. The locations of ground truth is denoted with the blue dots.

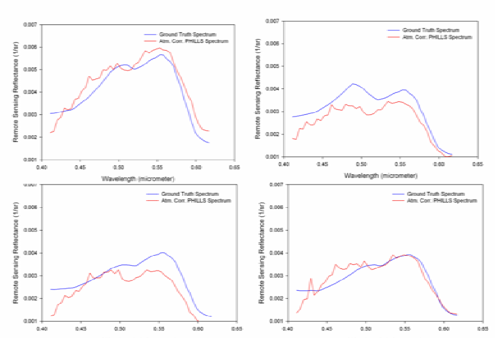

Figure 6b: The comparison of the best multi-GA TAFKAA corrected PHILLS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	1.575
Ozone	[.30,.45]	0.3015
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.137
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	80%
Aerosol Model	[urban, maritime, coastal, coastal-a, tropospheric]	maritime

Table 1: The parameters for the San Luis, CA (October 27th 2002) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA.

employed four in our analysis. We choose our stations based on the fit between the simulated and observed measurements (see Figures 7a-b). Ideally, we should have been able to use all of the ground support data. Unfortunately, the misfits between many of the simulated and observed in-situ data (Figure 7b) made it very difficult to use many of the stations for our atmospheric procedures. This begs the question: why aren't the other station's fits better? Any number of possibilities, ranging from instrumentation error to Hydrolight model parameterization inaccuracies, could be used to explain the results. However in our investigation, we have become concerned with the subjective nature of the quality control in the in situ data processing. Also the lack of metrics developed to determine the precision and accuracy of the measurements is troubling. The current usefulness of the hyperspectral data is directly linked to the quality of the ground truth data sets. In an attempt to address our concerns, we have proposed some quality control measures to help institute objective and repeatable ground truth data processing. We have shared these concerns and remedies with our CI-CORE partners, and we are now developing the steps need to implement them.

The dependence of the hyperspectral atmospheric correction on the ground truth data sets is not ideal. We are evaluating procedures in which the GA would be best trained by the data itself. Ground truth data would be used only for validation purposes. The procedure is active research and still in it infancy. In the mean time, the procedure outlined here produced admirable results and thus, it will be employed in correcting the remainder of the data sets.

The remote sensing reflectance data from San Luis Bay are used in Figure 8a. This Figure shows our first quantitative attempts at separating kelp from bottom reflectance and resuspended sediments. The larger background image is a false color composite of atmospherically-corrected mosaic of San Luis Bay, CA (October 2002) using bands 443 nm, 580 nm, and 800 nm, and it shows kelp in bright red colors with a unique color signature (left and bottom inset) that is quantifiably different than the shallow waters, as well as the deeper waters off shore. The right inset shows a *Lingulodinium spp.* bloom (brown colors; M. Moline, CalPoly per. comm.) mixed with surface kelp in shallow waters. Again, the spectral signatures (bottom inset) allow for the quantifiable separation of Harmful Algal Bloom (HAB) forming dinoflagellates from surface kelp and shallow waters. These preliminary results will be

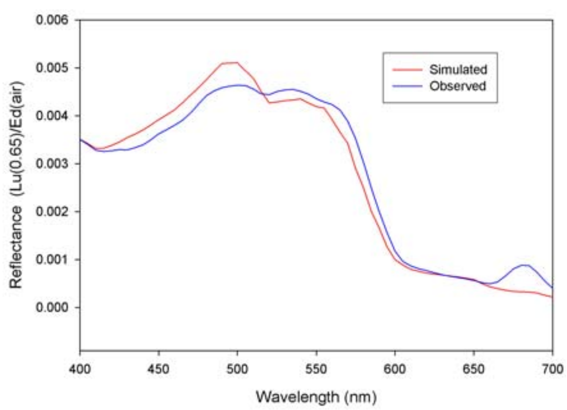

Figure 7a: Comparison of the observed and simulated ground truth spectra from San Luis Bay station six. There is relatively good agreement between the two signals.

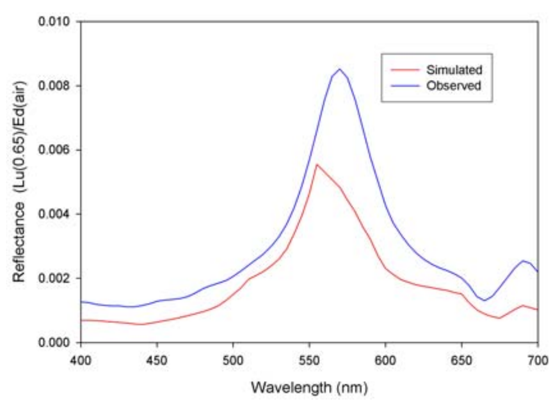

Figure 7b: Comparison of the observed and simulated ground truth spectra from San Luis Bay station one. While the general shape between the two signatures is similar, their magnitudes are very different. The observed signal is approximately double the simulated return.

expanded with further development of water quality and benthic habitat classification techniques during the following period.

A digitized kelp map was produced using a supervised classification scheme (Figure 8b). In this approach, the atmospherically-corrected 3 band data were used to create a map of kelp distributions based on a minimum distance technique using selected Region Of Interests (ROI) for examples of kelp, land, and water pixels. This is a subjective clustering technique which requires the analyst to establish scene-dependent rules for placing every pixel in the image within a representative cluster. This approach is a very useful technique when applied over limited areas, and within a single scene. The application of supervised classifications over larger areas becomes problematic, as the scene dependence clustering approach is time intensive and requires a subjective choice of cluster vector (in this case via a ROI) for each image set. The greatest use of the HSI data will be through objective cluster techniques, which uses a pre-described full hyperspectral vector, i.e. hyperspectral library vector, for kelp. This approach may be combined with a Look-Up-Table (see below) that will also allow for the determination of percentage cover for each pixel, as the relative reflectance of each pixel is de-mixed from the surrounding reflecting water, and kelp beneath the surface. These are products under development by CI-CORE.

An objectively produced digitized kelp product is a tremendous advancement over current Infra-Red (IR) film products. The conversion of IR film products to digital imagery requires many steps, and depending on the type of film and camera used has varying levels of

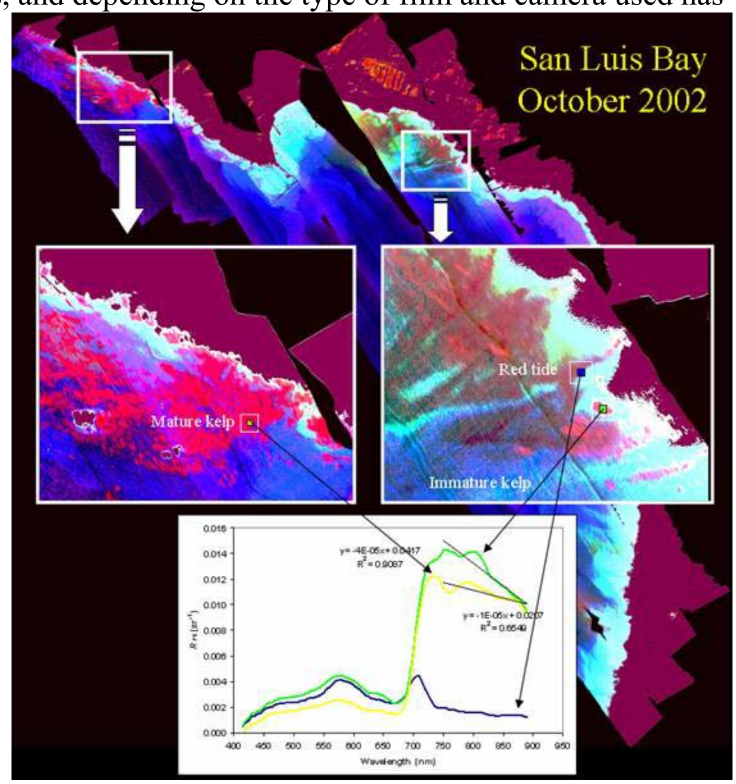

Figure 8a: False color composite of atmospherically-corrected mosaic of San Luis Bay, CA (October 2002) using bands 443 nm, 580 nm, and 800 nm. This product is used to help delineate kelp distributions. Top left inset show mature kelp canopy distributions (shown in bright red) in clearer oceanic waters (dark blue), mixed near-shore with sediment laden waters (aquamarine). The left inset shows less mature kelp canopies mixed with near-shore sediment laden waters, as well as with high concentrations of Lingulodinium spp. (shown in brown).

digital separation in the kelp signal. The first step is to take the image and scan it into a computer. These films must be geo-rectified, and depending on the user processing, must be tonally balanced for illumination. (The alternative to tonal balancing is to process each film individually, which is a very intensive/expensive process.) For black and white IR films, the only distinguishing feature is a bright broadband signal in the water, and the intensity of the signal from the film must be mapped into some numerical representative of a digital greyscale value, e.g. white areas are given a value of 255, black areas a value of 0, for an 8 bit digitization. The user then selects the greyscale value which corresponds to a kelp feature and all pixels which have a greyscale value at this point or above is considered kelp. Pixels containing mixtures of kelp and water are arbitrarily selected as either kelp, or not kelp. Land values are subjectively excluded. This last step is similar to the supervised classification described previously, with the exception that this supervised classification used in Figure 8b is based on the calibrated, atmospherically-corrected remote sensing reflectance values. These are true radiometric quantities, which may be validated in the field, and use multiple bands for the selection of the cluster vector, and cluster threshold. While this spectral supervised classification has a “man-in-the-loop”, it does so on real, quantifiable, digital data. When HSI data are further used with an objective hyperspectral technique, the HSI approach will produce not only digitized kelp coverage products, but also estimates of canopy coverage per pixel, as well as the identification of kelp at depth. This last product is not possible at all with IR film products. These products will be done without the man-in-the-loop, for all of the scenes, in a quantifiable manner.

The HSI element of the CI-CORE program is focused on developing these objective products. However, they are not current deliverables of the CI-CORE program, in part because

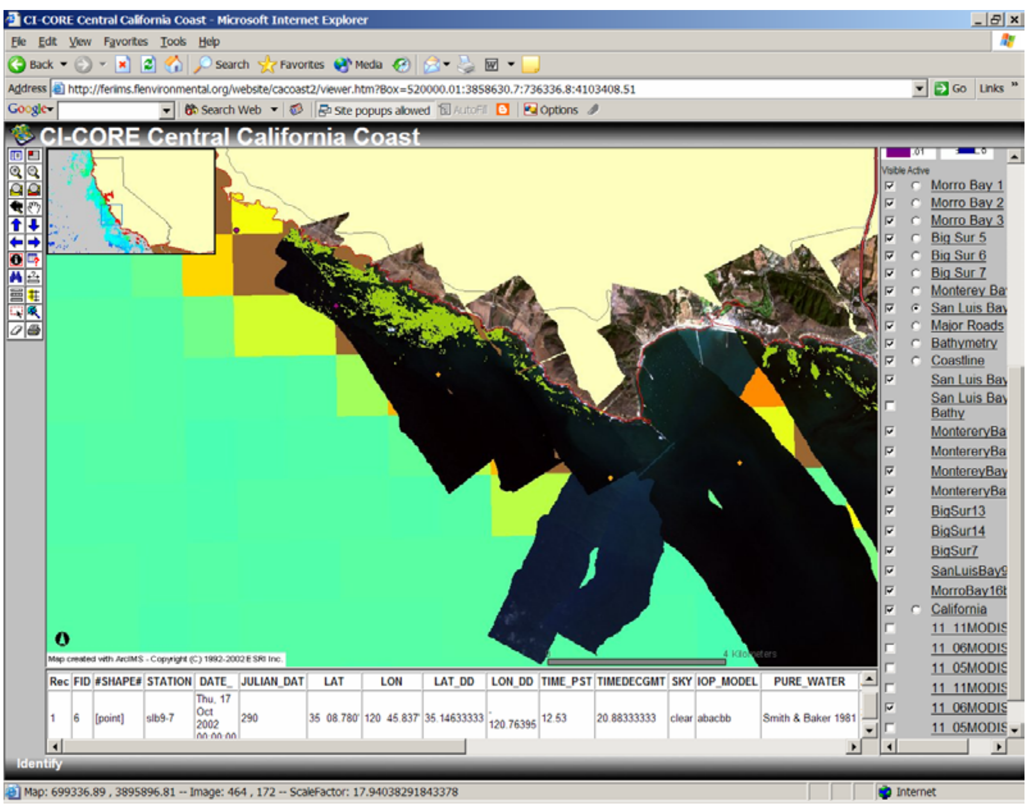

Figure 8b: Kelp distribution for the area north of San Luis Bay. Distributions produced by a supervised classification using bands 443, 580, 800nm. Cluster vector and threshold set by analyst to optimize kelp discrimination against water and land background.

our requested funding levels have not been met. This has led to our current focus of collection, calibration, and validation of the HSI data, as opposed to the production of products for other regions outside of the evaluation target region of San Luis Bay. Our view is that properly produced calibrated, validated HSI data may be used for product generation at some point future. However, if the HSI data were not ever collected, or if collected, but not processed accurately, there is no way to go back in time to recreate the data stream.

It was requested that we provide a cost comparison between IR film kelp products and HSI kelp products. This is difficult to do, because we are not in the IR film business and have no real quantifiable means of estimating the costs of producing those products. It can be safely said that while the initial collection of IR film may be inexpensive, the processing is not. It is extremely labor intensive and therefore cost intensive. Any comparisons of cost between digital spectral products and IR film products should be done at the product stage, not at the data collection stage. In addition, there is no way to avoid the subjective nature of the IR film product production. If we avoid the issue of geo-rectification, the tonal balancing, greyscale mapping, and greyscale kelp level selection are all subjective choices by the IR analyst. This forever puts the man-in-the-loop, and provides no scalability to product generation, or objective future error analysis in time series studies. In terms of scientific comparisons, the HSI data streams provide a means to access additional information, such as percentage coverage and subsurface kelp identification. These are not possible with the IR film products. HSI data offers the coastal community a future direction for effective management of valuable resources, and its costs should be scaled according.

Another hyperspectral derived product under development is a Look Up Table (LUT) based bathymetric map. In cooperation with Dr. Heidi Dierssen (University of Connecticut) and Dr. Richard Zimmerman (Old Dominion University), we have implemented a LUT approach to developing bathymetric map products from the atmospherically corrected hyperspectral data. Dr. Dierssen developed a simple LUT consisting of eight spectra based on ground truth data collected in San Luis Bay. The look-up table was constructed using simulations from the radiative transfer model, Hydrolight. Inputs to the model included the absorption and attenuation spectra measured at San Luis Bay Station 3 using an *ac*-9, particle phase function corresponding to the Fournier Fourand 14, Pope and Fry pure water absorption, 5 knot winds, and a semi-empirical sky model with cloud-free skies. The simulations included the bottom reflectance of sand measured in Monterey Bay (Wittlinger and Zimmerman, in prep) at depths varying from 1-7 m (Figure 9). The waters were determined to be optically deep at approximately 7-8 m when the remote sensing reflectance spectra matched that modeled with an infinite bottom.

The radiative transfer simulations were also conducted for a hard bottom comprised of red algae. The red algae spectrum used in the analysis was measured in Monterey Bay. As shown in Figure 9, red algae absorb much more of the incident light than sand and the resulting remote sensing reflectance spectra are lower. The imagery from San Luis Bay was screened to determine whether any of the measured spectra had a characteristic peak in the 560-590 nm region of the spectra. Specifically, the ratio of 570 nm to 530 nm was found to be less than 1 for all of the pixels in the image. This suggests that red algae bottoms were not detected in the imagery. More analysis must be conducted to determine whether the red algae spectra can be reliably used in the supervised classification without resulting in misclassifications of darker pixels as red algae instead of infinitely-deep bottom.

The seven sand spectra and the infinite spectra in Figure 9 were selected as "endmembers" (i.e., training classes) and used to conduct a supervised classification of the imagery. A minimum distance technique was employed to classify each pixel to the nearest endmember in the wavelength range from 450-650 nm. This spectral region was chosen to maximize the fit on the most distinguishable region of the spectra (green region, 540-590 nm) and to minimize any influences at the tail ends of the spectra. These influences include chlorophyll fluorescence, which were not included in the simulations and the exponentially increasing absorption of light by water at longer wavelengths, which lowers the signal-to-noise of the PHILLS II data stream. This LUT classification technique was coded into FERI's in-line mapping programs to efficiently estimate the bathymetry for every 2 m pixel in the entire San Luis Bay scene (see Figure 10).

We have used some of the initial in situ data to atmospherically correct two of the Monterey Bay collects (October 1st AM and 2nd AM, 2002). In both of these sets, we again chose to use only a portion of the possible ground truth stations due to our confidence in the measurements. We would like to address quality control issues on the in situ data before proceeding with product generation, as a significant change in the in situ data results will cause a significant amount of reprocessing.

The final major issue addressed is the distribution of the PHILLS II data. The cost and time needed by us to make these releases is substantial. Our CalPoly CI-CORE (PI – Mark Moline) partner currently serves the entire calibrated, geo-rectified data set in flight line form. However, these forms are difficult for the average user to handle, as the files are large and require specialized software to render usable information. To address the accessibility issue, we have developed a password secured web interface (Figure 11; http://www.flenvironmental.org/HyDRO/login.asp) that allows users to geographically select and download PHILLS II data of interest. Additionally, the user is offered the flexibility of selecting band combinations and ground spatial resolutions that better meet their needs. Once a request has been submitted and processed the user is notified by email and directed to an ftp site to

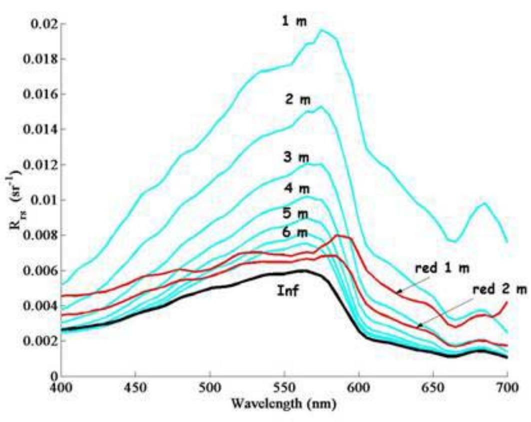

Figure 9: Remote sensing reflectance (R_{rs}) modeled using the radiative transfer model, Hydrolight, using in situ optical properties at various bottom depths (1-7 m). The blue spectra are those modeled with a sandy bottom and the red spectra are those modeled with a red algae bottom.

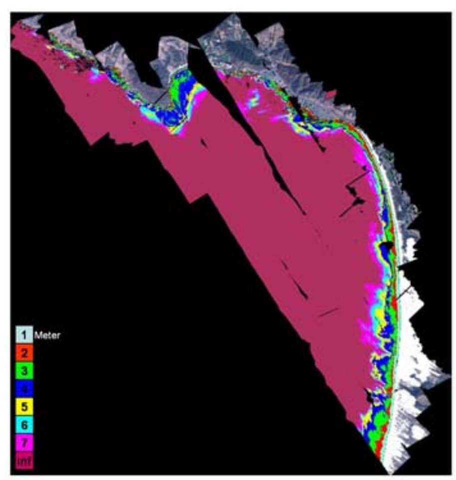

Figure 10: Bathymetry of San Luis Bay determined from remote sensing imagery obtained with the PHILLS II sensor.

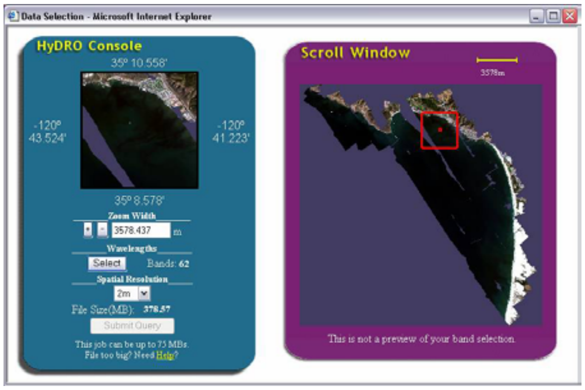

Figure 11: A screen shot of the FERI Hyperspectral Data Repository Online (HyDRO).

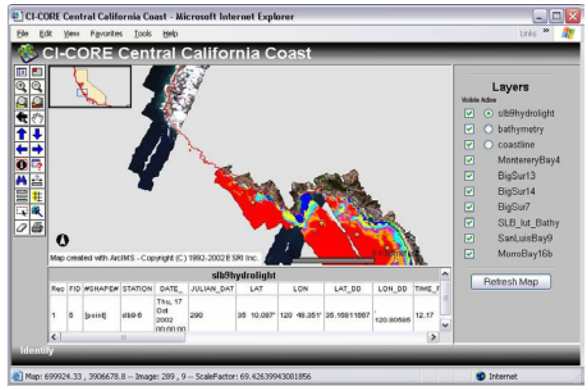

Figure 12: A screen shot of the FERI Arc Internet Map Server (ArcIMS).

download their request. It is hoped that this automation will better serve the research community while helping to alleviating the time and financial costs to FERI associated with distributing these large data sets. To date all of the radiometrically calibrated, geo-rectifed CI-CORE Fall 2002, data sets are on line. Currently only the San Luis Bay and Monterey 1 and 2 are atmospherically corrected (the others are radiometrically corrected to the sensor). As the remainder gets processed, the site will be updated.

In addition to the distribution of flight data, we are also developing an ArcIMS GIS site to serve a wider user community. This site (http://feriims.flenvironmental.org) contains reduced resolution RGB images of all flight data, with pointers to FGDC compliant metadata files, as well as ancillary in situ data collected during the course of flight operations (Figure 12). This site will be expanded with the addition of a SQL server to supply access to users of advanced CI-CORE data products.

Deliverable Results:

The following are the results from the anticipated deliverables list originally proposed:

1) The conditions necessary to collect the 2 m data have been describe in previous progress reports. These are available on request.
2) The radiometrically-calibrated, geo-rectified flight data are available from two on-line locations (FERI at http://www.flenvironmental.org, and CalPoly at http://www.marine.calpoly.edu/cicore/default.shtml).
3) Bathymetry estimates from hyperspectral data for target area of San Luis Bay (Figure 10). This data will also be available on-line on the FERI ArcIMS server.
4) Maps of bottom substrate from hyperspectral data for target area of San Luis Bay. The discernable bottom substrate in Figure 10 was sand bottom. However, further analysis and ground truthing needs to be completed to ascertain if other bottom types may be discernable.
5) Maps of kelp distribution for target area of San Luis Bay (Figure 8).
   i. the extent to which bull kelp and giant kelp can be distinguished was not possible with the target area data for lack of ground truth data.
   ii. the extent to which condition or "health" of the kelp canopy can be determined from the hyperspectral imagery was preliminarily determined based on spectral slope ratio in the NIR (Figure 8a, inset). Additional

validation data will need to be acquired to ascertain the predictability of this relation.

Summary

We have completed our geo-rectification and atmospheric correction of the October 2002 data collection and have developed the hardware and software tools to more accurately and quickly collect, calibrate, and geo-rectify airborne collected high resolution hyperspectral imaging data. We have developed our first products of surface kelp and potential HAB distributions in San Luis Bay, as well as bathymetric and bottom classification estimates. Future collects will demonstrate time-dependent change in previously collected areas, as well as expand the area of interest for the CI-CORE effort.